NASA/CR-2013-217920

Severe Weather Tool using 1500 UTC Cape Canaveral Air Force Station Soundings

William H. Bauman III
ENSCO, Inc., Cocoa Beach, Florida
NASA Applied Meteorology Unit, Kennedy Space Center, Florida

August 2013

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National Aeronautics and
Space Administration

Kennedy Space Center
Kennedy Space Center, FL 32899-0001

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Acknowledgements

The author wishes to thank Mr. William Roeder of the 45th Weather Squadron (45 WS) for lending his statistical expertise to this work and for developing and testing best-fit curves for determining the frequency of occurrence of severe weather.

The 45 WS launch weather officers and forecasters also provided valuable feedback on the methodology used and the development of the graphical user interface.

Finally, thanks to Mr. Stephen Madison of Computer Sciences Raytheon, who helped trouble-shoot the AMU code and install the operational software on the Meteorological Interactive Data Display System.

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Executive Summary

Customers: NASA's Launch Services Program (LSP)
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People and property at Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS) are at risk when severe weather occurs. Strong winds, hail and tornadoes can injure individuals and cause costly damage to structures if not properly protected. NASA's LSP and GSDO Program along with other programs at KSC and CCAFS use the daily and weekly severe weather forecasts issued by the 45th Weather Squadron (45 WS) to determine if they need to limit an activity such as working on gantries, or protect property such as a vehicle on a pad. Missed lead-times and false alarm rate statistics show that severe weather in east-central Florida is difficult to forecast during the warm season (May-September).

Due to the threat severe weather poses to life and property at the Eastern Range and the difficulty in making the forecast, the 45 WS requested the Applied Meteorology Unit (AMU) develop a warm season severe weather tool for use in the Meteorological Interactive Data Display System (MIDDS) based on the late morning, 1500 UTC (1100 local time), CCAFS (XMR) atmospheric balloon sounding. The 45 WS frequently makes decisions to issue a severe weather watch and other severe weather warning support products to NASA and the 45th Space Wing in the late morning, after the 1500 UTC sounding, which is more representative of the atmospheric instability than the early morning, 1000 UTC, sounding. A tool using the 1500 UTC sounding should improve the accuracy and timeliness of severe weather notifications provided by the 45 WS to and help decision makers implement appropriate mitigation efforts.

The results of this task indicate the proper use of certain stability indices and parameters based on the late morning XMR soundings can improve the forecasters ability to identify days with a severe weather threat. The AMU calculated a Total Threat Score (TTS) for every 1500 UTC sounding in the 24-year database and compared the TTS to reported severe weather occurrences on each day with a sounding. From this, they determined a frequency of reported severe weather for each TTS and developed an operational tool in MIDDS. The AMU's new tool eliminated 83% of the subjective questions posed to the forecasters in the previous MIDDS tool, thereby streamlining the process of running the tool in MIDDS and creating a more objective assessment of the daily warm season severe weather threat. This should contribute directly to the 45 WS goal of improving severe weather warning capability for its NASA, US Air Force and commercial customers.

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1. Introduction

People and property at Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS) are at risk when severe weather occurs. Strong winds, hail and tornadoes can injure individuals and cause costly damage to structures if not properly protected. NASA's LSP and GSDO Program along with other programs at KSC and CCAFS use the daily and weekly severe weather forecasts issued by the 45th Weather Squadron (45 WS) to determine if they need to limit an activity such as working on gantries, or protect property such as a vehicle on a launch pad. Missed lead-times and false alarm statistics show that severe weather in east-central Florida is difficult to forecast during the warm season (May-September). Due to the threat severe weather poses to life and property at the Eastern Range and the difficulty in making the forecast, the 45 WS requested the Applied Meteorology Unit (AMU) develop a warm season severe weather tool for use in the Meteorological Interactive Data Display System (MIDDS) based on the late morning, 1500 UTC (1100 local time), CCAFS (XMR) atmospheric balloon sounding. The 45 WS frequently makes decisions to issue a severe weather watch and other severe weather warning support products to NASA and the 45th Space Wing in the late morning after the 1500 UTC sounding, which is more representative of the atmospheric instability than the early morning 1000 UTC sounding. A tool using the 1500 UTC sounding should improve the accuracy and timeliness of severe weather notifications provided by the 45 WS to help decision makers implement appropriate mitigation efforts.

1.1 Previous Tasks

The AMU developed the Severe Weather Forecast Decision Aid (Bauman et al. 2005) based on the 1000 UTC (0600 local time) XMR sounding that used a Hyper-Text Markup Language graphical user interface (GUI). The period of record (POR) included the warm season months for the years 1989-2003. The decision aid was modified for use with a MIDDS GUI in 2009 (Wheeler 2009) and then data from the 2004-2009 warm seasons was added in 2010 (Wheeler 2010). In 2011 (Watson 2011), data from the 2010 warm season was added to the decision aid, verification statistics were calculated for the Total Threat Score (TTS) and statistical logistic regression analysis was performed on the 22-year severe weather database. The 2011 results indicated that the logistic regression equation did not show an increase in skill over the previously developed TTS. Therefore, the only change to the version of the decision aid developed in Wheeler (2010) was the inclusion of 2010 data in the database.

1.2 Current Work

The POR for this task was the warm season months in the 24 years 1989-2012. This 1500 UTC sounding-based tool builds upon the previous work conducted in development of the 1000 UTC sounding-based tool. The AMU took advantage of using some of the existing databases and methodologies described in the previously referenced reports to create this tool. Besides using the late morning soundings for this work, the AMU eliminated 83% of the subjective questions posed to the forecasters in the previous GUI, thereby streamlining the process of running the tool in MIDDS and creating a more objective assessment of the daily warm season severe weather threat. The AMU discovered the subjectivity in the previous GUI sometimes resulted in different severe weather threat assessments for the same day when used by different forecasters. Also, the AMU's statistical analysis determined that some of the parameters were not relevant when considering the severe weather threat. For example, on 95% of the days with reported severe weather, there was no severe weather reported on the previous day. Therefore the questions about persistence in the previous GUI were eliminated. Table 1 provides a summary of each question from the previous GUI, whether or not the

question was eliminated in the new 1500 UTC GUI and the reason why the question was removed or remained.

Table 1. Summary of the parameters from the previous severe tool GUI that were eliminated (shaded red) or carried over (shaded green) into the new 1500 UTC GUI.

GUI Question	Eliminated?	Reason
Is severe weather mentioned in the FXUS62 bulletin?	Yes	Forecasters sometimes inferred severe weather from other terms used such as "strong".
Was severe weather mentioned in the previous bulletin?	Yes	The previous bulletin was not relevant for the current day.
Was severe weather reported by Tampa or Melbourne?	Yes	Persistence was not relevant 95% of the time.
Was severe weather reported by Tallahassee or Jacksonville?	Yes	Persistence was not relevant 95% of the time and these reports were geographically irrelevant.
Is there a front/squall line in northwest Florida moving southeast?	Yes	Forecasters did not always agree on the answer to this question – too subjective.
Is there a distinct moist/dry boundary across central Florida?	Yes	Forecasters did not always agree on the answer to this question – too subjective.
Do the sounding winds veer with height from surface to 10,000 feet?	Yes	On days with reported severe weather the winds were veering 40% of the time and backing 60% of the time.
Is there a 200 mb speed max, right entrance region, left exit region or divergence near?	No	The position of a 200 mb speed max was directly related to days with reported severe weather.
What is the flow regime?	No	The flow regime was directly related to days with reported severe weather.
If a sea breeze forms will it stay east of I-95?	Yes	While relevant, it could not be objectively quantified. The new GUI has a statement reminding the forecasters to consider this parameter.
Are you forecasting a late developing sea breeze?	Yes	While relevant, it could not be objectively quantified. The new GUI has a statement reminding the forecasters to consider this parameter.
Are you forecasting or observing multiple boundary collisions?	Yes	While relevant, it could not be objectively quantified. The new GUI has a statement reminding the forecasters to consider this parameter.

2. Data

The AMU had three existing data sets compiled during previous tasks that were used in this task after they were updated with 2011 and 2012 data. They included upper-level (200 mb) jet stream analyses, severe storm reports and daily flow regimes. The two new data sets required for this task were the 1500 UTC XMR soundings and the stability parameters derived from those soundings.

2.1 Existing Data Sets

To update the existing data sets, the AMU generated and then downloaded the 200 mb wind and streamline maps (Figure 1) from the Plymouth State University (PSU) Weather Center (2013; http://vortex.plymouth.edu/u-make.html) for the 2011 and 2012 warm seasons. The maps were analyzed to determine the jet stream position and the results were entered into the existing 1989-2010 AMU jet stream analysis database. Next, the AMU downloaded the 2011 and 2012 warm season severe storm reports from the National Climatic Data Center Storm Events Database (NCDC 2013; ftp.ncdc.noaa.gov/pub/data/swdi/stormevents) and then added the severe events for Brevard, Volusia, Indian River, Seminole, Osceola and Orange counties (Figure 2) to the existing 1989-2010 AMU severe storm reports database. Reports from the six counties were needed to make sure the database had enough events to derive meaningful

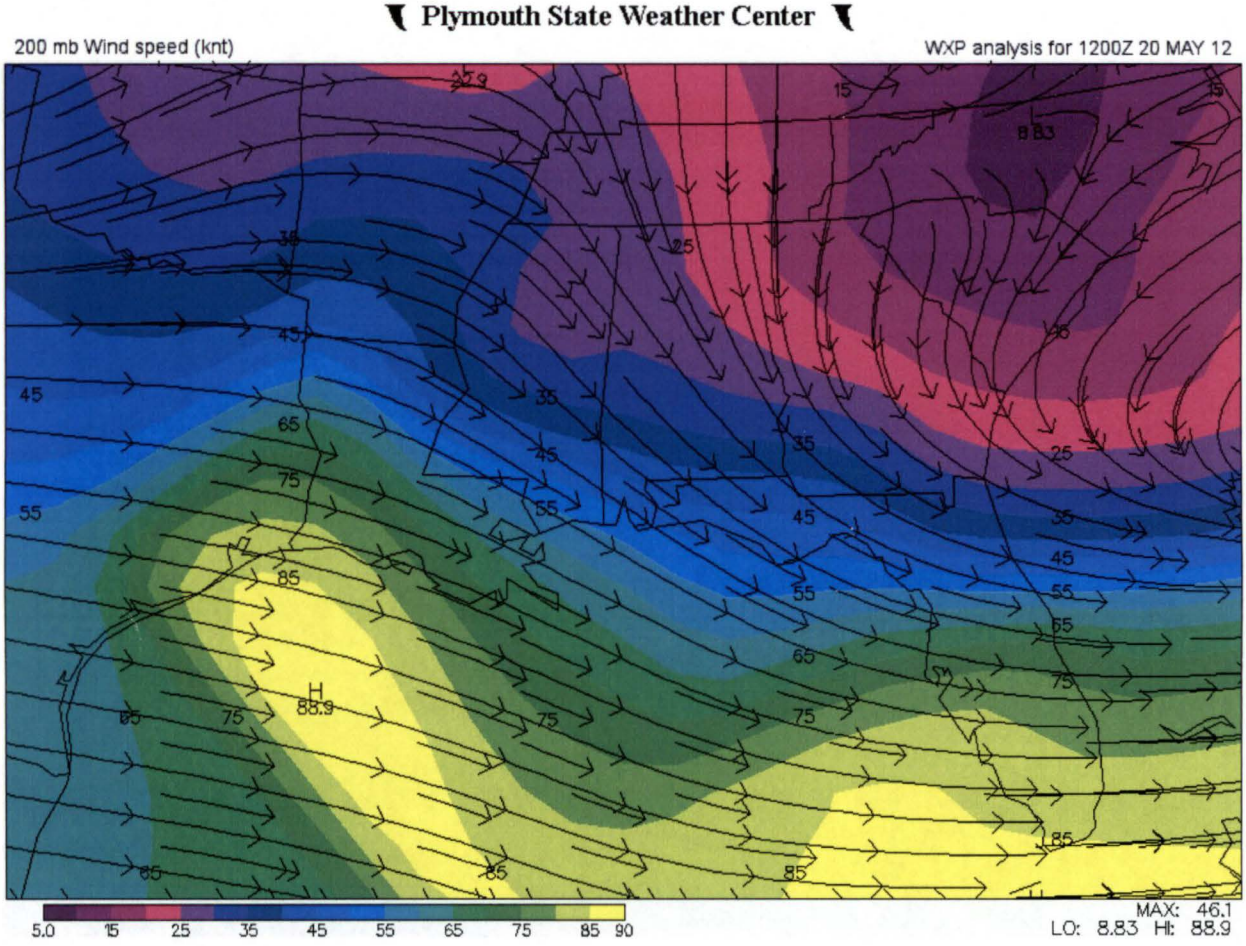


Figure 1. Example of a 200 mb wind and streamline map generated from the PSU Weather Center used in this work to identify the jet stream position. Lines with arrows indicate the wind direction and the shaded regions show the wind speed in kt.

statistical relationships since so few events occur in the KSC/CCAFS area. There are three coastal counties (Volusia, Brevard, Indian River) and three inland counties (Seminole, Orange, Osceola), all of which are typically in the same large-scale air mass as KSC/CCAFS on most warm season days. Even though these severe reports may not have occurred at KSC/CCAFS, they are still of interest since severe weather in relatively close proximity to the space center needs to be tracked for possible impacts to operations since the chance of severe weather is elevated at KSC/CCAFS under those conditions. The main triggers of convection in the warm season are the location, movement, and strength of the local sea breeze front and storm outflow boundary collisions. Severe weather events included tornadoes, waterspouts, convective surface winds ≥ 50 knots (≥ 26 ms^{-1}), and/or hail with a diameter ≥ 0.75 inches (≥ 1.91 cm) through 2009 and ≥ 1.00 inch (2.54 cm) after 2009. Finally, the AMU added the 2011 and 2012 daily flow regimes (Lambert 2007) to the 1989-2010 AMU flow regime database.

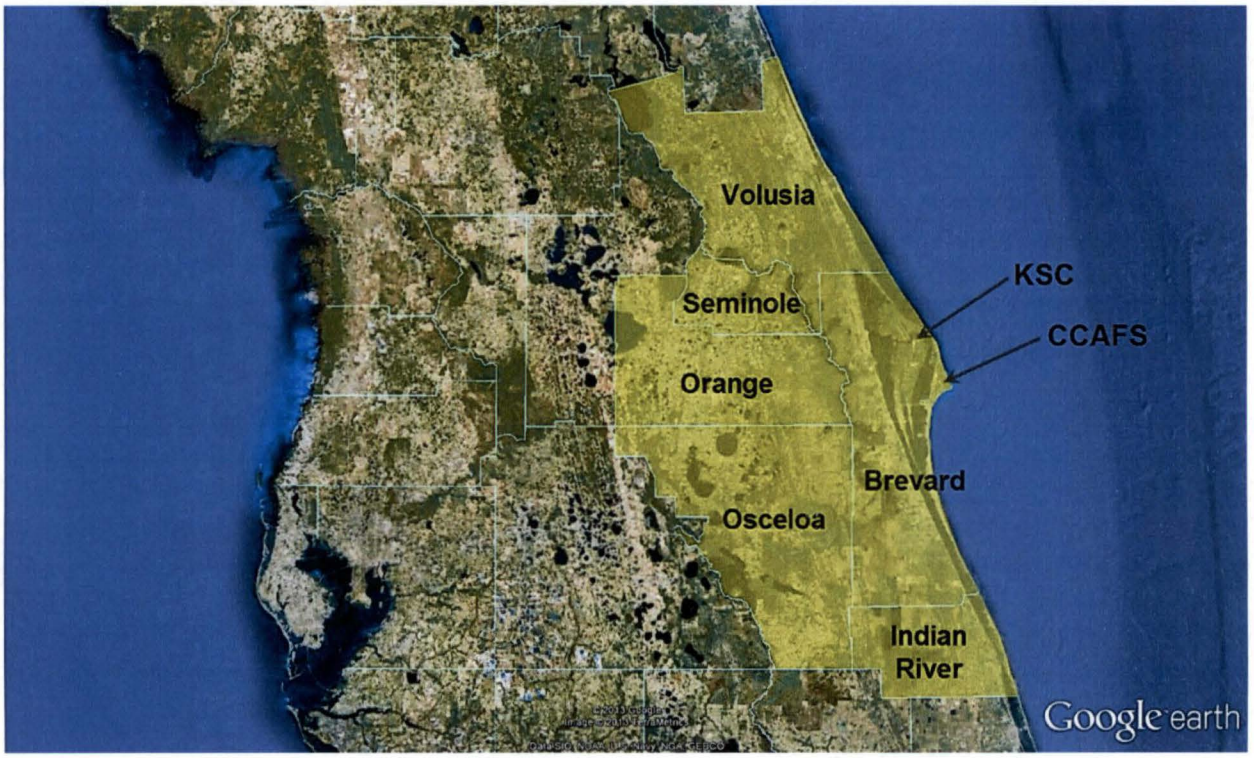


Figure 2. Map of central Florida showing the six counties (shaded in yellow) included in the severe weather events database. The location of KSC and CCAFS are shown on the map; both reside in northern Brevard County.

2.2 New Data Sets

To create the 1500 UTC sounding database, the AMU reformatted the original raw sounding files they received for previous tasks from Computer Sciences Raytheon (CSR) personnel. The reformatted files contained data from all rawinsondes released from May-September 1989-2012. Upon inspection, the AMU discovered the 1991 files only contained 1000 UTC soundings. The AMU requested and received the 1500 UTC soundings from May-September 1991 from CSR personnel at the CCAFS Weather Station.

The reformatted sounding files were in ASCII text format and were separated into files containing mandatory, significant and 1,000-ft levels for multiple years and months. The AMU reorganized these files into three files per year containing data from all soundings in May-September of each year: one mandatory, one significant and one 1,000-ft. They wrote scripts

using Visual Basic for Applications (VBA) in Microsoft Excel to process the sounding files as follows:

- extract the 1430-1530 UTC mandatory, significant and 1,000-ft level sounding data,
- merge the data into individual daily sounding files and save them as Excel spreadsheets,
- format the files to be processed by TIBCO Spotfire S+ (TIBCO 2010) scripts to generate the sounding stability parameters, and
- automatically quality control (QC) the soundings to remove duplicate levels, check for heights in meters instead of feet and check for multiple daily soundings between 1430-1530 UTC.

After running the VBA scripts, the AMU manually QC'd the data in the Excel spreadsheets flagged by the automated QC. For any days with multiple soundings between 1430-1530 UTC, they assessed each sounding and kept the one released closest to 1500 UTC or the most complete sounding. For any soundings with heights in both meters and feet, they deleted the rows with heights in meters, leaving complete soundings containing only heights in feet. Finally, they wrote a VBA script that merged each daily sounding file for each year into one Excel file per year. Twenty four years of warm season soundings resulted in a total of 2,842 days with one sounding released between 1430-1530 UTC out of a possible 3,672. The AMU removed 14 more soundings from the database on days when KSC/CCAFS was under the influence of a tropical cyclone and another 30 that failed QC checks due to missing data or physically impossible values, resulting in a total of 2,798 soundings.

To generate the stability parameters from the soundings, the AMU used existing and modified Spotfire S+ scripts. The following 24 severe weather indices and parameters were generated from the soundings:

- Lifted Index (LI)
- K-Index (KI)
- Thompson Index (TI)
- Showalter Stability Index (SSI)
- Total Totals (TT)
- Cross Totals (CT)
- Vertical Totals (VT)
- Severe Weather Threat Index (SWEAT)
- Convective Available Potential Energy (CAPE)
- CAPE based on the maximum equivalent potential temperature (CAPE Max θ_e)
- CAPE based on the forecast maximum temperature (CAPE FMaxT)
- Convective Inhibition (CIN)
- Precipitable Water (PW)
- Temperature at 850 mb (T_{850})
- Temperature at 500 mb (T_{500})
- Average relative humidity in the 1000-700 mb layer (Avg70RH)
- Average relative humidity in the 850-500 mb layer (Avg85RH)
- Average relative humidity in the 850-600 mb layer (Avg86RH)
- Microburst Day Potential Index (MDPI) (Wheeler 1996)
- Inversion height below 8 kft
- Wind speed $\geq$ 25 kt and wind direction $\geq$ 109° and $\leq$ 270° at 850 mb (850 Jet)
- Veering winds from surface to 10 kft (WarmAdv)
- Helicity
- Storm Relative Motion Speed and Direction

3. Stability Thresholds and Threat Scores

After generating the stability indices and parameters, the AMU categorized the days with reported severe weather and days without reported severe weather by threshold values for each index, and then developed charts showing the percent of time severe weather was reported based on specific thresholds. The thresholds were the same as those used in the Severe Weather Decision Aid (Bauman et al. 2005). An example using TT is shown in Figure 3. When the TT was in the low category (TT ≤ 45), severe weather was reported 11% of the time. When TT was in the medium category (46 ≤ TT ≤ 48), severe weather was reported 25% of the time. When TT was in the high category (TT > 48), severe weather was reported 45% of the time.

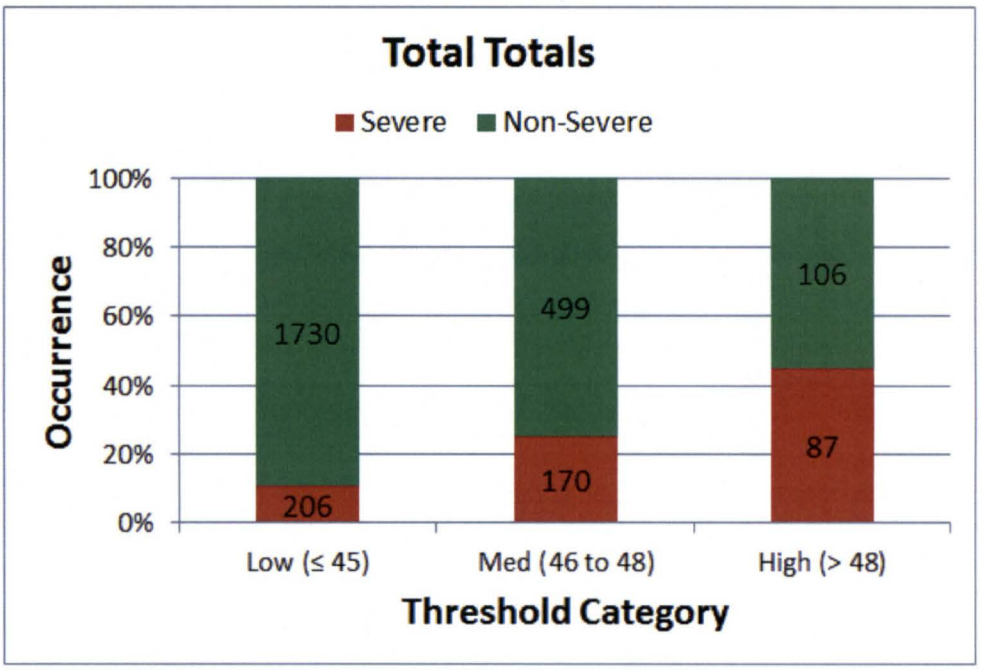


Figure 3. Stacked bar chart of TT for the low, medium and high threshold categories showing percent occurrence of the number of days with reported severe weather (red) and days with no reported severe weather (green).

The AMU used the categorized thresholds from each index to determine if they would be useful predictors of severe weather occurrence. They created a threat score for each index derived from the percent of time severe weather occurred in each threshold category. To scale the threat score between 0 and 10, they divided the percent value by 10. Based on this methodology, the TT threat scores for the Low, Med and High threshold categories were 1.1, 2.5 and 4.5. The AMU used these scaled threat score values as the basis to compute the TTS from multiple indices and parameters.

Figure 4 compares the threat score for each stability index in each category. Lines with steeper slopes show a correlation to reported severe weather by having low threat scores in the Low category increasing to higher threat scores in the High or Very High categories. Based on the slope of each line in Figure 4, the best stability index indicators of severe weather occurrence were SSI, TT, SWEAT, LI and VT as they had the largest increase in severe weather threat score from lowest to highest threshold category. The CT, TI and KI slopes were not as steep, representing a smaller threat score change across the threshold categories. Therefore, they were not as good as the other indices in their forecastability of severe weather between categories. Similarly, the thresholds of energy indices derived from the soundings are shown in Figure 5. The CIN, CAPE Max θ_e and CAPE FMaxT were the best energy index

indicators with slopes similar to the CT, TI and KI stability indices. Helicity, not shown in the charts was not incorporated into the tool because its threat score decreased across the low, medium and high categories.

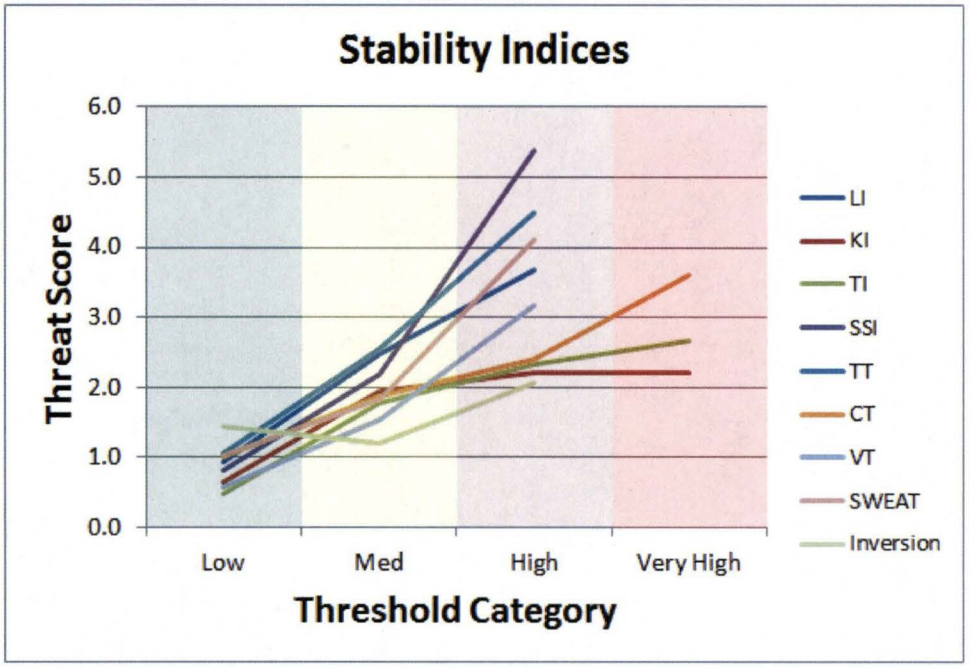


Figure 4. Line chart of stability indices showing the threat score for each index in each threshold category.

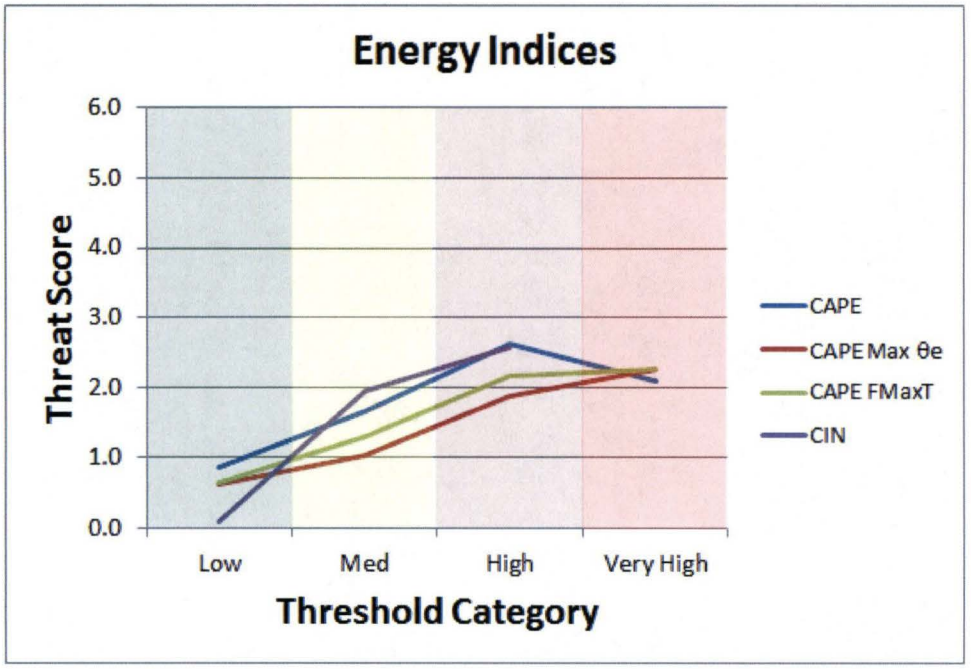


Figure 5. Line chart of energy indices showing the threat score for each index in each threshold category.

The AMU also considered moisture parameters derived from the soundings as severe weather indicators and the resulting chart is shown in Figure 6. The values of the Avg85RH and Avg86RH increase from the Low to Med threshold categories but then decrease at the High

threshold category indicating they are poor predictors and were not used in the tool. The Avg70RH and PW both increased across the threshold categories and were used as predictors.

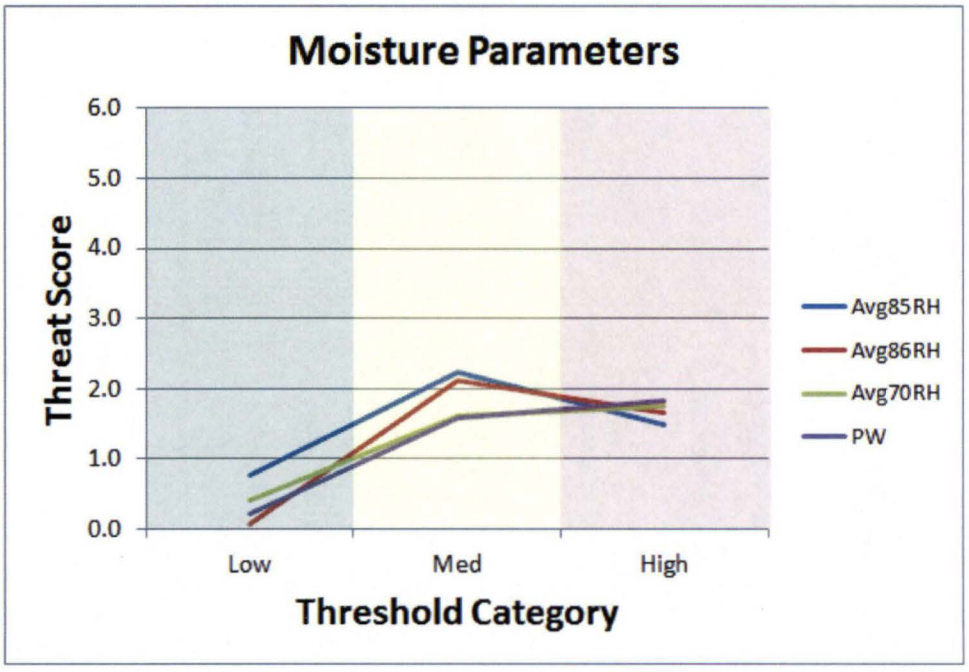


Figure 6. Line chart of moisture parameters showing the threat score for each parameter in each threshold category.

The other parameters considered as possible indicators of severe weather are shown in Figure 7. They include T_{850}, MDPI, 850 Jet, WarmAdv and T_{500}. Of these parameters, only the 850 Jet showed a significant enough correlation to reported severe weather that it was incorporated into the tool.

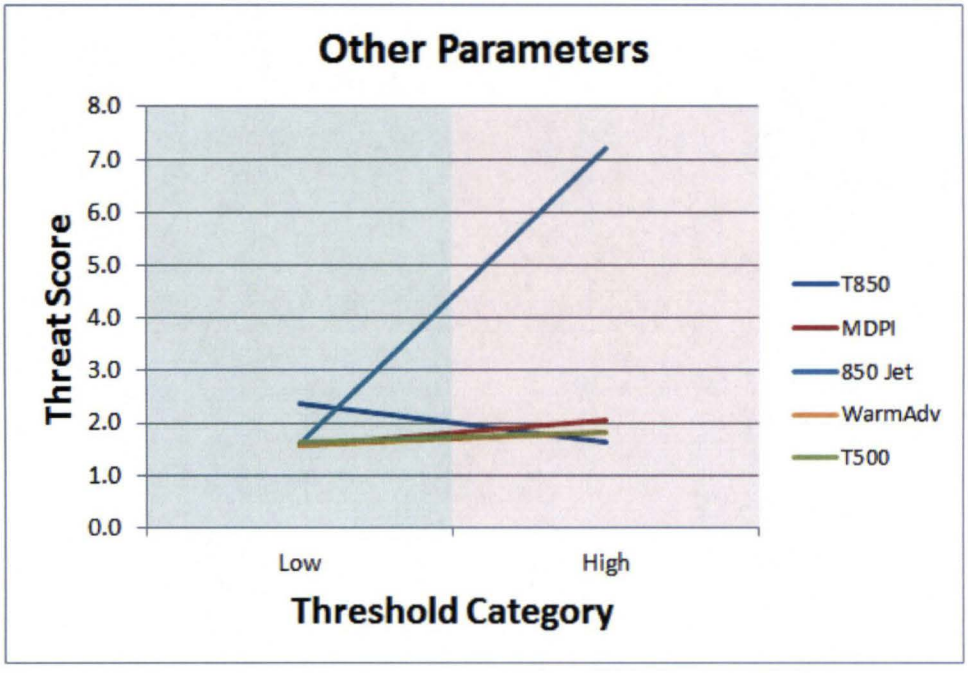


Figure 7. Line chart of other parameters showing the threat score for each parameter in two threshold categories.

Non-sounding based parameters known to contribute to severe weather potential include the peninsular flow regime (Lericos et al., 2002) and the 200 mb jet position (Uccellini and Johnson 1979). Previous research indicated the flow regime had some influence on the frequency and intensity of convective winds (Ander et al., 2009). The threat scores for each of the flow regimes are shown in Figure 8. The two westerly regimes, northwest (NW) and southwest (SW), result in the highest threat scores because those regimes favor thunderstorm movement towards east Florida. The highest threat scores based on the 200 mb jet position (Figure 9) relative to east-central Florida occur under the influence of left exit, right entrance and divergence regions.

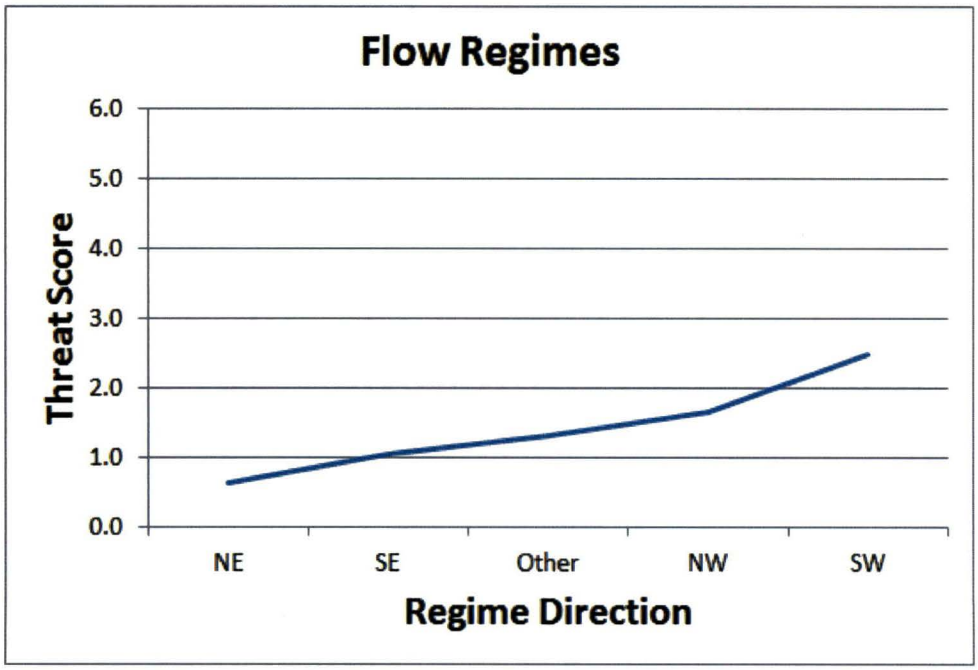


Figure 8. Line chart of flow regimes and corresponding threat scores.

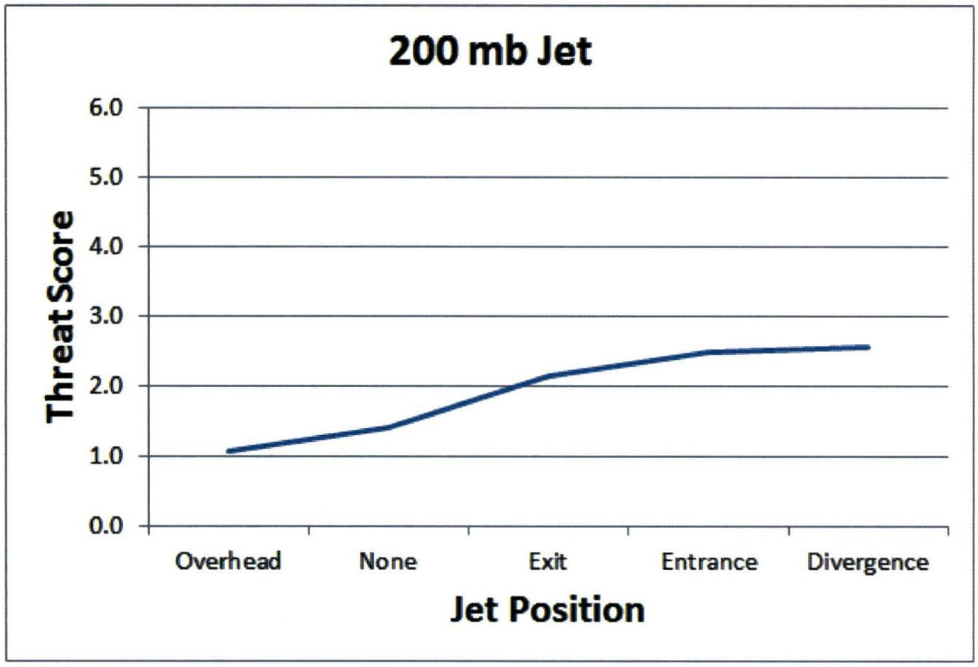


Figure 9. Line chart of 200 mb jet and corresponding threat scores.

The AMU compiled the results of all parameter's threat scores for each sounding, flow regime and 200 mb jet position for the 24-year database in two Excel spreadsheets. One spreadsheet compiled the threat scores for each day with reported severe weather and the other for days with no reported severe weather. Figure 10 shows a sample of the spreadsheet with threat scores for days with reported severe weather. The daily TTS was determined by summing the individual threat scores from each parameter in each row. On days with reported severe weather, the TTS ranged from 15 to 50 with a median of 30. On days with no reported severe weather, the TTS ranged from 12 to 41 with a median of 22.

Date			Stability and Moisture Threat Scores																Raw	Rounded
Year	Month	Day	LI	KI	TI	SSI	TT	CT	VT	PW	SWEAT	CAPE FMaxT	CIN	Flow Regime	Jet Position	LLJet	MDPI	RH700	TTS	TTS
1989	MAY	1	0.9	0.7	0.5	0.8	1.1	1.0	3.2	1.7	1.0	0.6	2.6	2.5	2.6	1.6	1.6	1.7	24.1	24
1989	AUG	9	0.9	0.7	0.5	0.8	1.1	1.0	1.5	1.7	1.8	2.2		2.5	2.1	1.6	1.6	1.7	21.7	22
1989	AUG	10	2.5	0.7	1.8	0.8	1.1	1.0	0.6	1.7	1.0	2.2	1.0	2.5	2.1	1.6	1.6	1.7	23.9	24
1990	JUN	26	2.5	2.2	2.7	2.2	2.5	2.4	3.2	1.7	1.8	2.3		1.1	2.1	1.6	1.6	1.7	31.6	32
1990	JUL	2	3.7	2.2	2.7	5.4	4.5	3.6	3.2	1.7	1.8	2.3		1.7	2.6	1.6	1.6	1.7	40.3	40
1990	JUL	12	2.5	2.2	2.3	2.2	2.5	2.4	3.2	1.7	1.8	2.2		1.1	2.6	1.6	1.6	1.7	31.6	32
1990	JUL	22	2.5	2.2	2.3	2.2	2.5	2.4	1.5	1.7	1.8	2.3	1.0	2.5	2.6	1.6	1.6	1.7	32.4	32
1990	JUL	25	2.5	2.2	2.3	2.2	2.5	1.9	3.2	1.7	1.8	2.3		1.3	1.4	1.6	1.6	1.7	30.2	30
1990	AUG	3	2.5	2.2	2.7	2.2	2.5	2.4	1.5	1.7	1.8	2.3		2.5	1.4	1.6	1.6	1.7	30.6	31
1990	AUG	9	2.5	2.2	2.3	2.2	2.5	1.9	1.5	1.7	1.8	2.3		2.5	2.6	1.6	1.6	1.7	30.9	31
1990	AUG	10	0.9	2.2	1.8	0.8	1.1	1.0	1.5	1.7	1.8	1.3		2.5	2.1	1.6	1.6	1.7	23.6	24
1990	AUG	13	2.5	2.2	2.3	2.2	2.5	1.9	1.5	1.7	1.8	2.3	1.0	1.1	2.1	1.6	1.6	1.7	30.0	30
1991	MAY	31	2.5	2.2	1.8	2.2	4.5	1.9	3.2	1.7	1.8	1.3	2.6	1.7	2.6	1.6	1.6	1.7	34.9	35
1991	JUN	14	2.5	2.2	2.7	2.2	4.5	3.6	1.5	1.7	1.8	2.2		1.1	2.6	1.6	1.6	1.7	33.5	34
1991	JUN	18	2.5	2.2	2.7	2.2	2.5	3.6	1.5	1.7	1.8	2.3	1.9	2.5	2.6	1.6	1.6	1.7	34.9	35
1991	JUL	10	2.5	2.2	2.3	0.8	1.1	1.0	1.5	1.7	1.8	2.3	1.9	2.5	2.6	1.6	1.6	1.7	29.1	29
1991	JUL	15	3.7	2.2	2.3	2.2	4.5	2.4	3.2	1.7	1.8	2.3	1.9	1.1	1.4	1.6	2.1	1.7	36.1	36
1991	JUL	16	3.7	2.2	2.7	5.4	4.5	3.6	3.2	1.7	1.8	2.3	1.0	2.5	2.6	1.6	2.1	1.7	42.6	43

Figure 10. A portion of the Excel spreadsheet used to calculate the TTS for each day based on the sounding parameters, flow regime and 200 mb jet position.

Initially, similar to the previous AMU Severe Tool, the AMU categorized the TTS as shown in Table 2. The top row of bold-face numbers shows the TTS categories for days with reported severe weather. The second row shows the number of days in each TTS category. The third row shows the frequency of occurrence of days in each TTS category. The bottom row shows the frequency of occurrence of days with reported severe weather in each TTS category.

Table 2. Number of days with reported severe weather in each of seven TTS categories, the frequency of the number of days with reported severe weather in each TTS category and the frequency of the occurrence of reported severe weather in each TTS category.

	TTS Categories							
	≤ 14	15-19	20-24	25-29	30-34	35-39	≥ 40	Total
Number of severe days	0	9	60	159	173	51	11	463
Frequency of severe days	0%	2%	13%	34%	37%	11%	2%	100%
Severe report occurrence	0%	1%	6%	21%	57%	72%	92%	

The TTS distribution for days with reported severe weather and for days with no reported severe weather should demonstrate the ability of the TTS to indicate the severe weather potential. Figure 11 shows the distributions of days with and without reported severe weather. While there is some overlap, the maxima of the distributions are distinct, indicating the TTS distribution provides insight into the severe weather potential. On days when severe weather was reported, the TTS was ≥ 30 during 50% of those days. On days with no reported severe weather the TTS was ≥ 30 during 6% of those days. Conversely, when the TTS was ≤ 24, 69% of the days had no reported severe weather while 15% of days had reported severe weather.

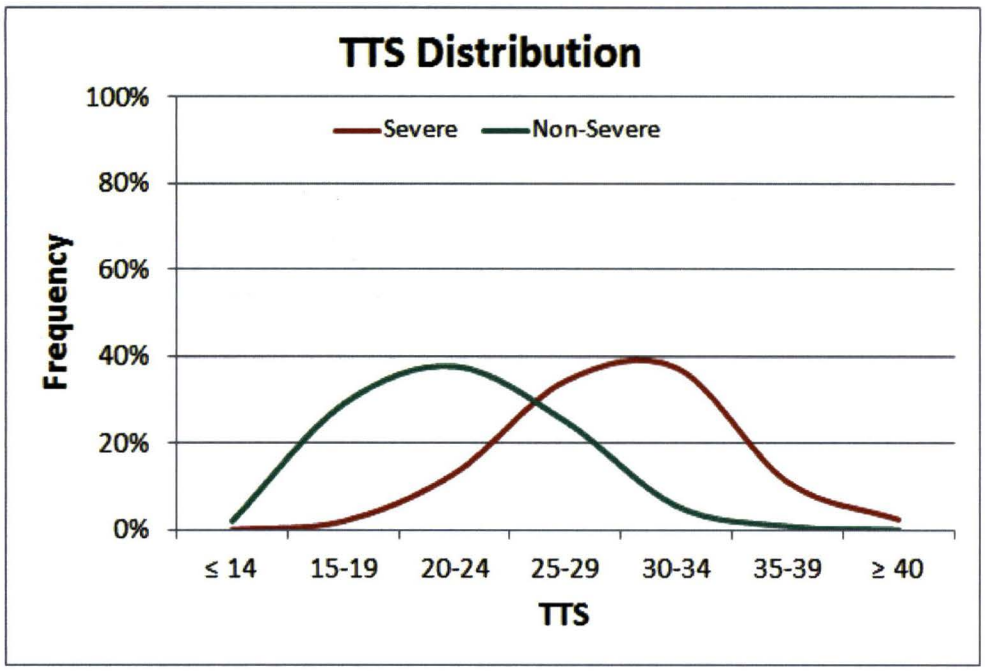


Figure 11. The TTS distribution on days with reported severe weather (red line) and days with no reported severe weather (green line).

Another consideration for forecasters would be the occurrence of reported severe weather based on TTS category. For example, as Figure 12 illustrates, when the TTS was ≥ 40, severe weather was reported 92% of the time. While that is significant, looking at Table 2, only 2% of days with reported severe weather were in this TTS range. So, while this TTS category does not occur often, when it does occur, severe weather is very likely. This is as expected since severe weather is rare, a good predictor indicating severe weather should likewise occur infrequently.

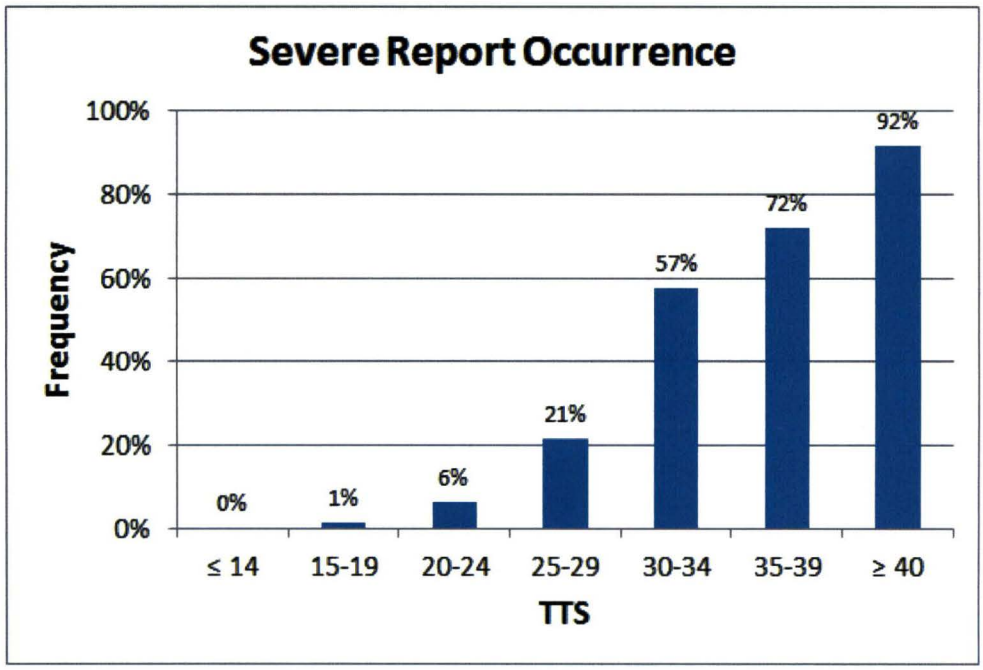


Figure 12. The distribution of reported severe weather frequency based on seven TTS categories.

After discussing the TTS categories with the forecasters, the AMU decided the seven numerical categories may be too broad to provide quality guidance to the forecasters and considered using single TTS values instead of categories to provide higher fidelity output of the frequency of occurrence of reported severe weather. Figure 13 shows a line chart of each TTS value. While this methodology provides higher fidelity, it also has more noise than the categorical data—especially at higher TTS values with a smaller sample size.

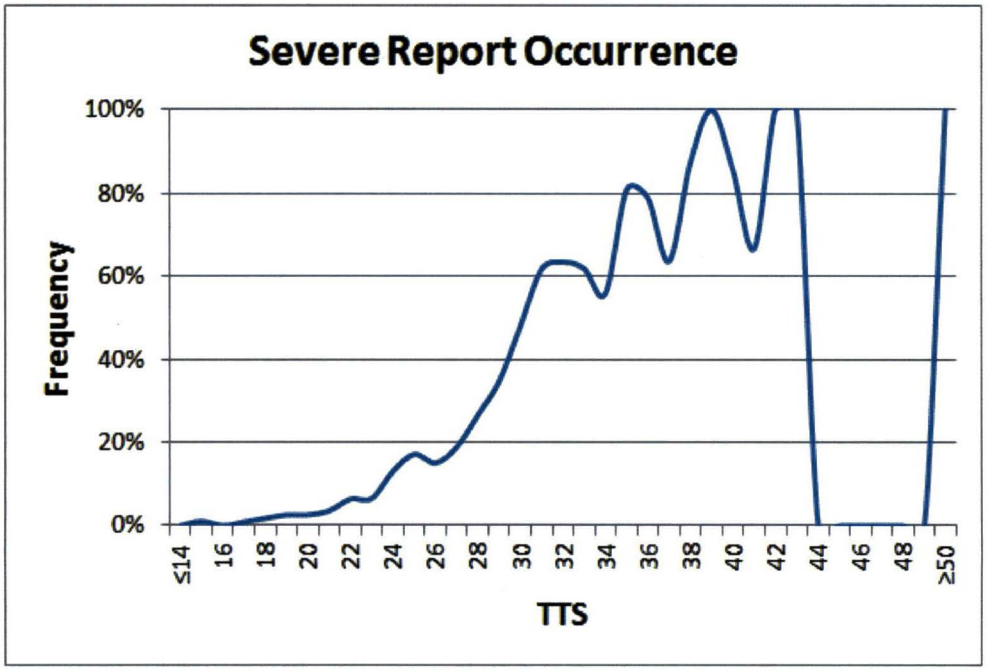


Figure 13. The distribution of reported severe weather frequency based on individual TTS values.

To help minimize the noisy data and create a more useful tool for the forecasters, the AMU fit several types of curves to the data including logarithmic and polynomial. A second order polynomial is shown in Figure 14. However, the polynomial curve reached a maximum of 59% at a TTS of 37 and fell below 0% at a TTS of 18. Further examination of the distribution in Figure 12 and Figure 13 suggest a logistic curve response. A best-fit logistic curve would maintain the increased fidelity while reducing the noise.

Mr. Roeder from the 45 WS offered to do a best-fit logistic curve since the logistic curve is constrained to be within 0% to 100% and is often used in probabilistic regression. Fitting a logistic curve cannot be solved analytically and must be done iteratively, in this case manually due to lack of statistical software. Each of the three coefficients was step-wise iterated until the RMSE of the differences between the logistic curve and the observed values was minimized. The iteration was cycled until the coefficients changed by less than 0.0005 (optimized to three decimal places).He also tested other best-fit curves (quadratic, exponential, and power law) for completeness in case they performed better. These three curves exceeded 100% at the higher TTS values, similar to the second order polynomial curve. The best-fit logistic regression curve is specified by the following formula and is shown in Figure 15.

$$y = 100 * \left(\frac{1}{1 + exp\left(-\left(0.764 + 0.270 * (x - 34.013)\right)\right)} \right)$$

The logistic curve is a better fit to the data than the other methods and offers the additional desired behavior of not being able to exceed 100% at large TTS values or falling below 0% at low TTS values. The mean difference between the actual data and the logistic curve is -0.66 indicating the logistic curve is slightly more conservative overall. The best-fit logistic curve offers just over a 19% improvement over the original categorical approach and that improvement is a higher probability of severe weather, which is conservatively safer.

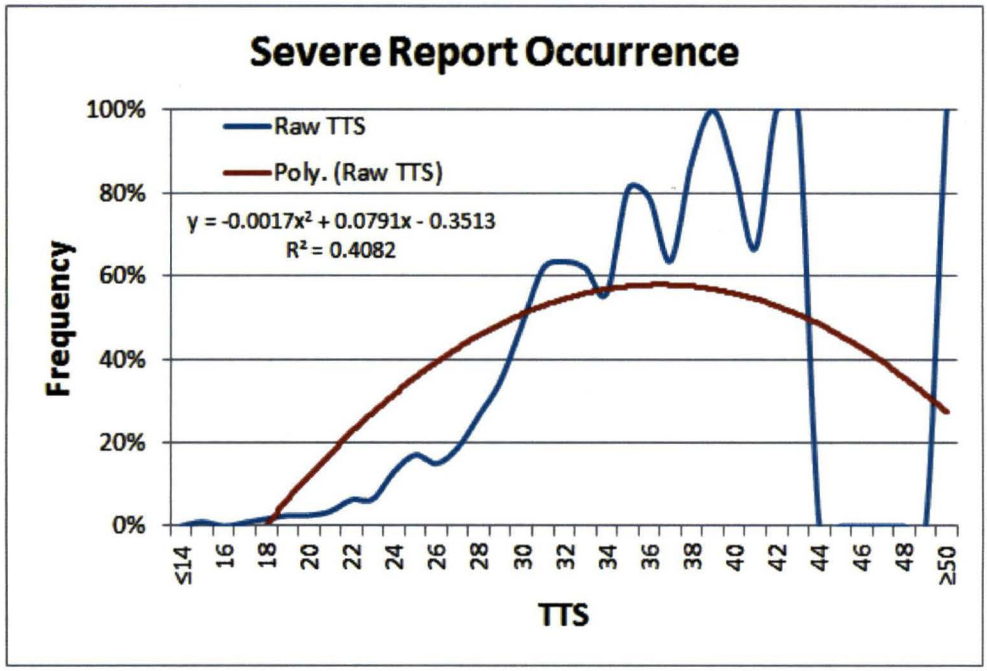


Figure 14. As in Figure 13 with a second order polynomial curve (red line) fit to the TTS values (blue line).

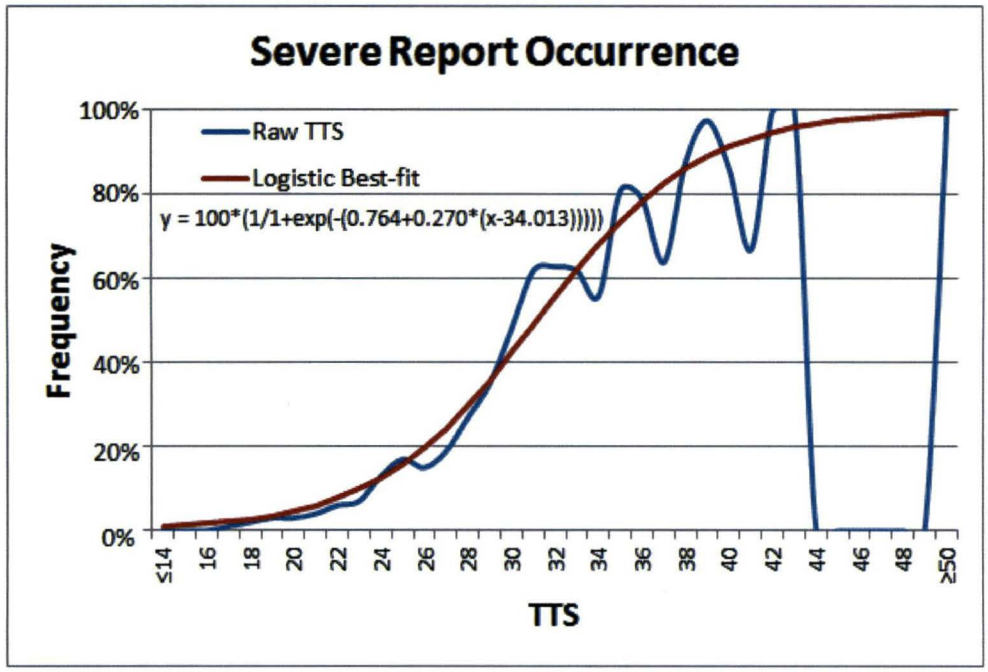


Figure 15. As in Figure 13 with a best-fit logistic regression curve (red line) fit to the TTS values (blue line). A correlation coefficient (R^2) is not available because best-fit logistic curves must be done iteratively and manually.

Table 3 shows the final TTS values and corresponding occurrences of reported severe weather based on the logistic regression curve shown in Figure 15 that were implemented in the MIDDS GUI.

Table 3. The final TTS values (green shading) and corresponding occurrences of reported severe weather (red shading) based on the logistic regression curve fit.

TTS	≤14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Severe Freq (%)	1	1	2	2	3	4	5	6	8	10	13	16	20	24	30	36	42	49
TTS	32	33	34	35	36	37	28	39	40	41	42	44	45	46	47	48	29	≥50
Severe Freq (%)	56	62	68	74	79	83	86	89	92	93	95	97	98	98	99	99	99	99

4. MIDDS Tool

The AMU developed the 1500 UTC Severe Weather Tool in MIDDS using the Tool Command Language and its associated Tool Kit (Tcl/Tk). The user starts the tool from the main weather menu on MIDDS. The program executes the Tcl/Tk code to compute and retrieve sounding parameters and then presents the user with the GUI for manual input. Then the code computes a threat score for each parameter and the TTS for the sounding. The tool displays the output in two graphic windows for the user to view and saves two files in MIDDS for archive.

4.1 Graphical User Interface

When the user executes the program in MIDDS, the message shown in Figure 16 is displayed while MIDDS accesses the sounding data and calculates the parameters. Once the

Figure 16. Message window in MIDDS notifying the user that the program is acquiring the sounding data.

sounding parameters are ready, the GUI is displayed for the user to enter information about the 200 mb jet position and flow regime as shown in Figure 17. There is a Help button in the upper right of the GUI window that describes how to use the GUI and a description of the tool itself. The date is displayed in two formats just above the questions on the left: year and Julian day, and calendar day in month/day/year. The two gray buttons below the dates associated with each of the two questions provide a definition of each parameter via a pop-up window when the mouse is positioned over them. The user can also click one of the two white buttons at the right end of the row associated with each question to display maps in the MIDDS graphics window of the phenomena being assessed in order to answer the questions. Once the user clicks one of the gray buttons, the choice is displayed in the box at the far right of the window. After both choices are made, the user clicks the green box in the lower left to calculate the TTS. The GUI then closes and two other windows open with the results.

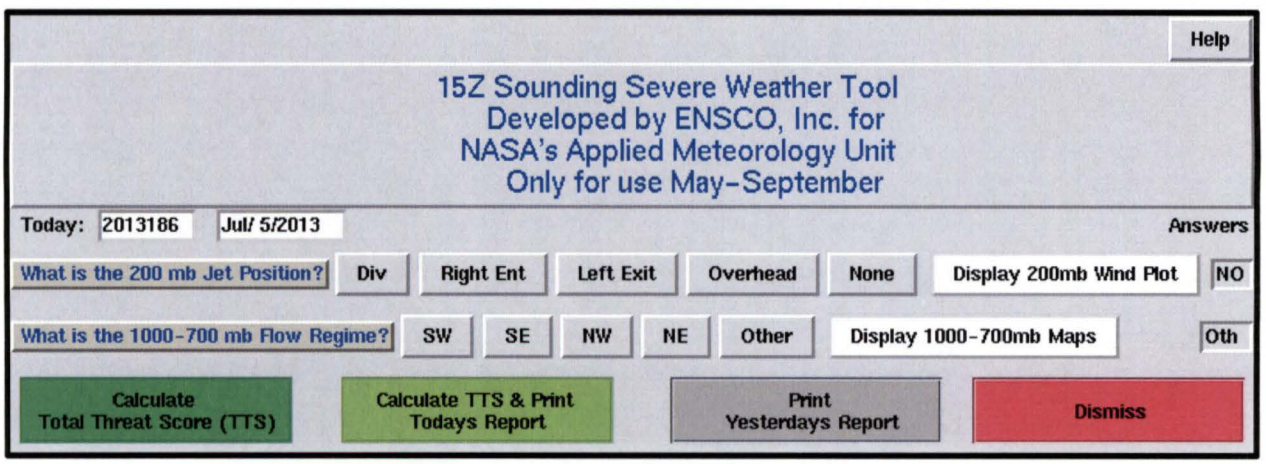


Figure 17. The 1500 UTC sounding-based Severe Weather Tool GUI.

4.2 Output Windows

The TTS, reported severe weather occurrence and associated information are shown in two windows in MIDDS. The first, shown in Figure 18, provides the user with a summary of the

output from the tool. The first group of text (black font) displays the current sounding's time and date, the TTS and the data set's range of the TTS values. The second group of text (red font) restates the TTS from the current sounding, displays the frequency of occurrence of reported severe weather based on the TTS and reminds the user that the data set is based on reported severe weather in six east-central Florida counties and the period of record was 1989-2012. The summary window was designed to give the user a quick look at the information output by the tool.

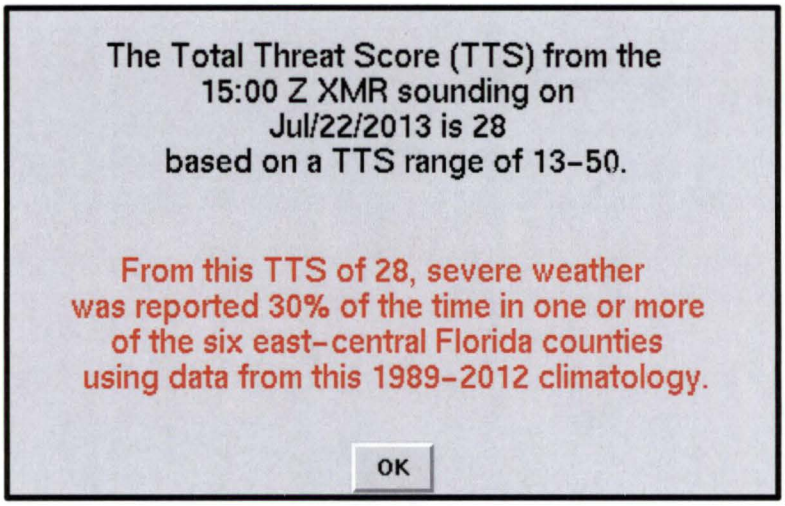
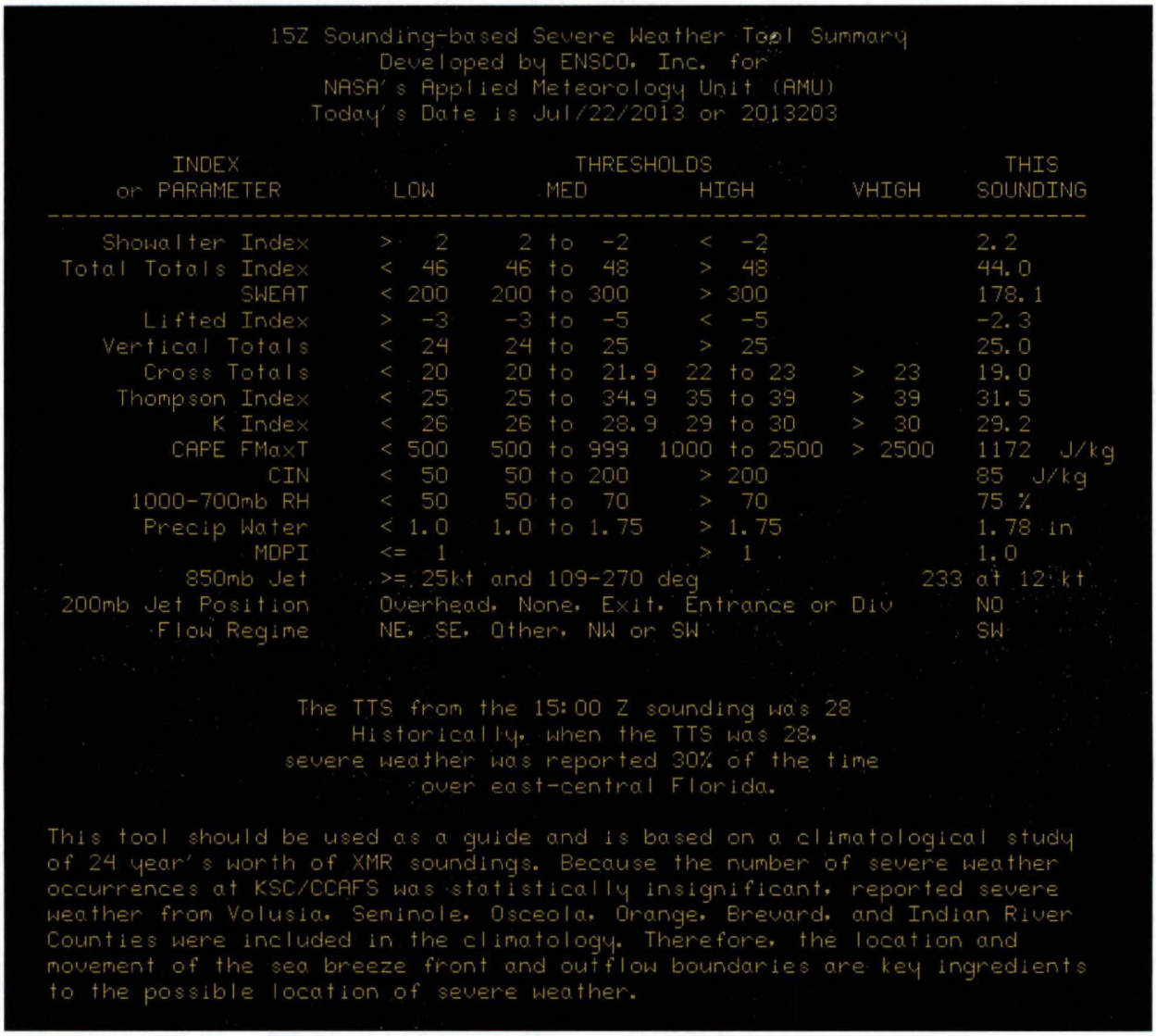


Figure 18. TTS summary window displayed in MIDDS provides a quick overview of the tool's output to the user.

The second window displayed, Figure 19, shows all of the sounding parameters and their values used to derive the TTS. The heading shows the month, day and year plus Julian date of the sounding. Below the heading is a table showing the index or parameter in the first (left) column. The next four columns show the low, medium, high and very high severe thresholds for each index or parameter to serve as a reference for the user. The last (right) column shows the value of the index or parameter from the sounding being evaluated. The next section of text below the table displays the time of the sounding, the TTS and the reported occurrence of severe weather based on the TTS. Finally, the paragraph at the bottom of the window serves as a brief reminder to the forecaster that this tool should be used as a guide when determining the severe weather potential on KSC/CCAFS for the day since the TTS value is based on a climatological study of severe weather occurrence in six east-central Florida counties. The forecaster must also consider the development and position of the sea breeze front and any outflow boundaries that could serve as triggers for convection and possibly lead to severe weather.

In addition to the two output windows, the AMU code saves two files to MIDDS for archive purposes. One is a comma separated value (CSV) formatted file that displays the Julian date, time, month, day and year of the sounding plus the indices and parameters with their associated values from the sounding. A CSV file can be viewed in Microsoft Excel as shown in Figure 20. The second file, shown in Figure 21, is saved in MIDDS as a text file that replicates the detailed TTS output window in Figure 19 and can be displayed in any text viewer software.



15Z Sounding-based Severe Weather Tool Summary
Developed by ENSCO, Inc. for
NASA's Applied Meteorology Unit (AMU)
Today's Date is Jul/22/2013 or 2013203

INDEX or PARAMETER	LOW	MED	HIGH	VHIGH	THIS SOUNDING
Showalter Index	> 2	2 to -2	< -2		2.2
Total Totals Index	< 46	46 to 48	> 48		44.0
SWEAT	< 200	200 to 300	> 300		178.1
Lifted Index	> -3	-3 to -5	< -5		-2.3
Vertical Totals	< 24	24 to 25	> 25		25.0
Cross Totals	< 20	20 to 21.9	22 to 23	> 23	19.0
Thompson Index	< 25	25 to 34.9	35 to 39	> 39	31.5
K Index	< 26	26 to 28.9	29 to 30	> 30	29.2
CAPE FMaxT	< 500	500 to 999	1000 to 2500	> 2500	1172 J/kg
CIN	< 50	50 to 200	> 200		85 J/kg
1000-700mb RH	< 50	50 to 70	> 70		75 %
Precip Water	< 1.0	1.0 to 1.75	> 1.75		1.78 in
MDPI	<= 1		> 1		1.0
850mb Jet	>= 25kt and 109-270 deg				233 at 12 kt
200mb Jet Position	Overhead, None, Exit, Entrance or Div				NO
Flow Regime	NE, SE, Other, NW or SW				SW

The TTS from the 15:00 Z sounding was 28
Historically, when the TTS was 28,
severe weather was reported 30% of the time
over east-central Florida.

This tool should be used as a guide and is based on a climatological study of 24 year's worth of XMR soundings. Because the number of severe weather occurrences at KSC/CCAFS was statistically insignificant, reported severe weather from Volusia, Seminole, Osceola, Orange, Brevard, and Indian River Counties were included in the climatology. Therefore, the location and movement of the sea breeze front and outflow boundaries are key ingredients to the possible location of severe weather.

Figure 19. Detailed TTS window displayed in MIDDS provides the user with index and parameter severe thresholds and the specific values derived from the current sounding used to generate the TTS.

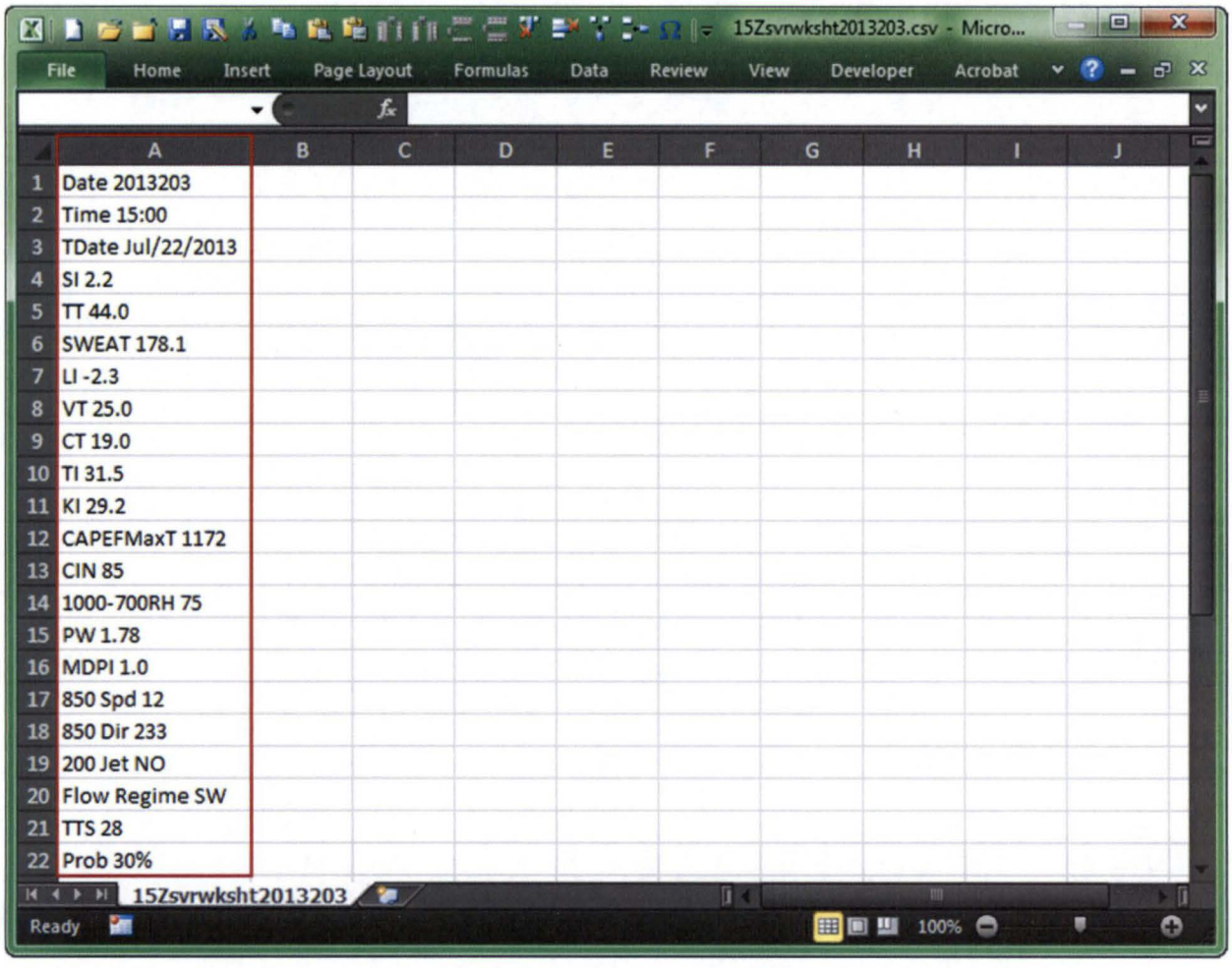


Figure 20. Sample output from a CSV file saved in MIDDS and displayed in Microsoft Excel. All of the output from the file is shown within the red rectangle in Column A of the spreadsheet.

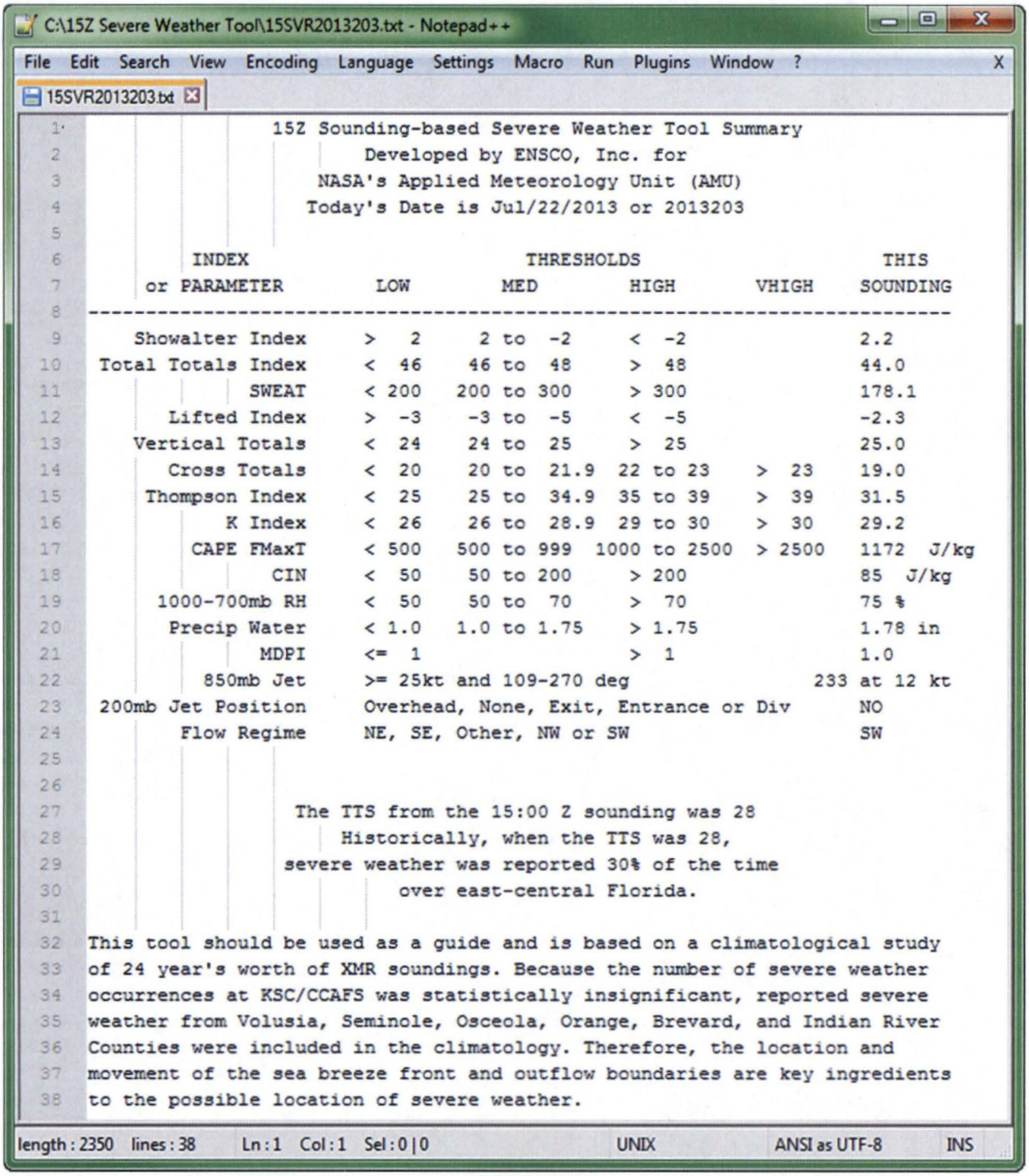


Figure 21. Sample output from a text file saved in MIDDS. The text file is identical to the output displayed in the detailed TTS window (Figure 19).

4.3 Testing and Training

The AMU tested the tool by running it each day a sounding was available to ensure MIDDS was calculating the correct values. Each parameter's threat score and resulting TTS was manually calculated to make sure they were identical to the corresponding threat scores calculated by the code in MIDDS for each sounding. To automate this process, the AMU wrote

code in Microsoft Excel VBA that imported the MIDDS CSV files (Figure 20) and calculated each parameter's threat score and the TTS to compare to the manually calculated values. The code was tested on 14 soundings to make sure it worked before discontinuing manual calculation of the threat scores and TTS. The AMU tested 40 soundings by comparing values from the MIDDS CSV files to the Excel-calculated values and ensuring consistent values before installing the software on the operational MIDDS.

In order to allow the forecasters to start using the tool during the current warm season, the AMU provided training to the 45 WS during two of their daily weather discussions in mid-July 2013. Presenting the training on two different days ensured all shift workers were present for the training. The AMU presented a very short overview of the work and then demonstrated how to use the tool in MIDDS. A more formal briefing covering all aspects of the task will be scheduled during a monthly training day.

5. Current 1000 UTC Severe Weather Tool

The AMU presented a status briefing on the progress of the 1500 UTC Severe Weather Tool to the 45 WS staff in May 2013. During the briefing, the 45 WS asked if the AMU could apply the same methodology into development of a new, updated 1000 UTC tool. They stated the existing 1000 UTC tool was based on too many subjective questions and preferred replacing the current MIDDS 1000 UTC GUI (Figure 22) with a GUI similar to the 1500 UTC tool since it is more objective.

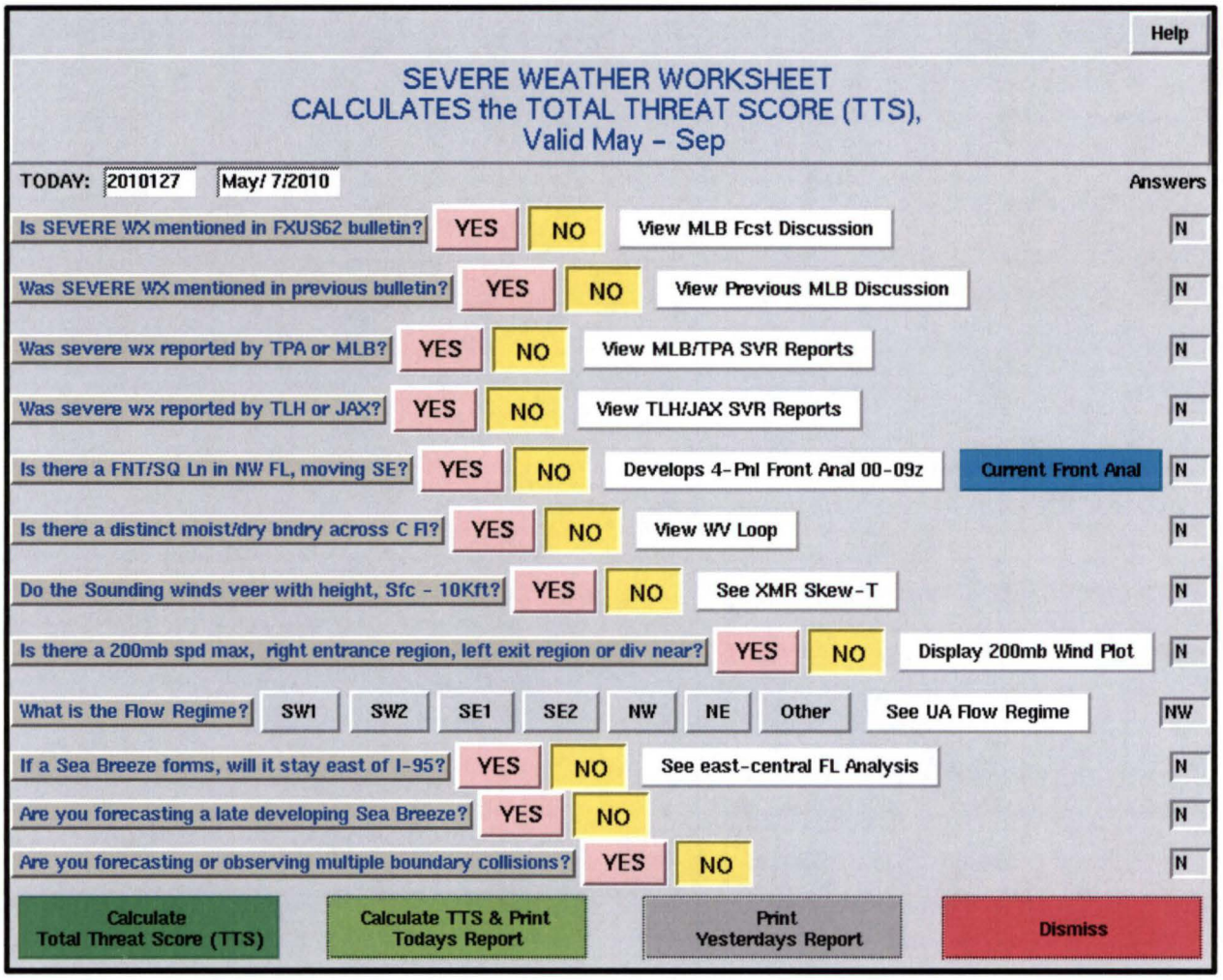


Figure 22. The existing 1000 UTC sounding-based Severe Weather Tool GUI.

The AMU stated that it would probably take only two to three weeks to implement this methodology in an updated MIDDS GUI using the 1000 UTC soundings because all of the stability parameters from the 1989-2012 1000 UTC soundings were previously calculated and readily available on the AMU server. During this status briefing, the KSC Weather Office authorized the AMU to undertake the work providing it did not delay the 1500 UTC sounding-based task. Since the 1500 UTC task was approximately two weeks ahead of schedule, there would be time to create a more objective 1000 UTC tool.

The AMU imported the 1000 UTC sounding data into the Excel spreadsheets developed for the1500 UTC tool and determined threat scores and a TTS for each sounding using the VBA scripts written for the 1500 UTC tool. The Tcl/Tk code was modified in MIDDS to process the 1000 UTC soundings and output the threat scores, TTS and occurrence of reported severe

weather based on the 1000 UTC parameters. The AMU simultaneously tested and implemented the updated 1000 UTC tool using the same methodology as for the 1500 UTC tool and developed a similar MIDDS GUI as shown in Figure 23.

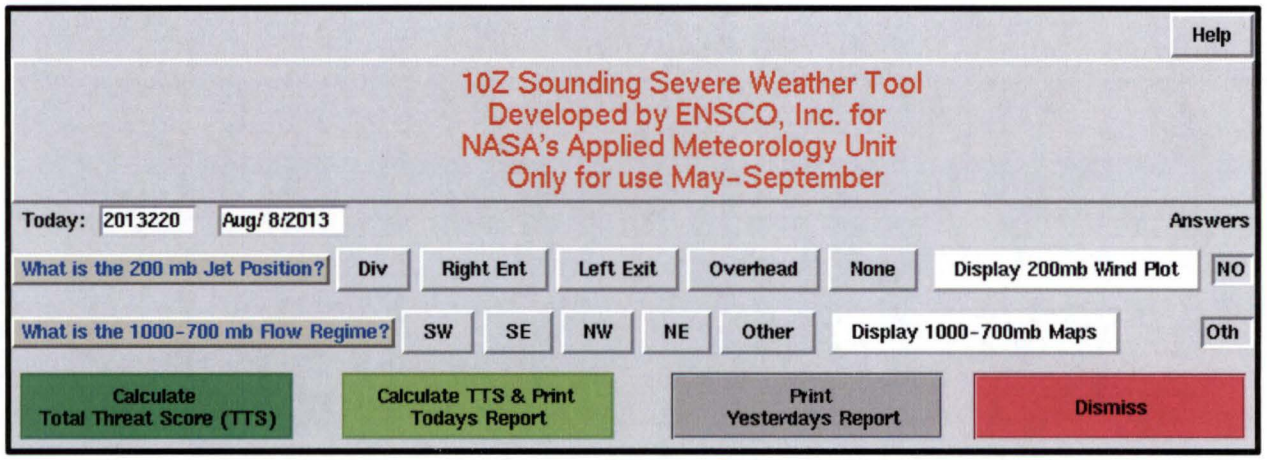


Figure 23. The new 1000 UTC sounding-based Severe Weather Tool GUI.

Unlike the 1500 UTC TTS distributions (Figure 11), the 1000 UTC TTS distributions assessed for the updated 1000 UTC tool show little difference between days with reported severe weather and days with no reported severe weather as shown in Figure 24. This data indicates the 1000 UTC tool may not be a good predictor of severe weather potential but more investigation and a more complete statistical analysis is warranted to verify this fact.

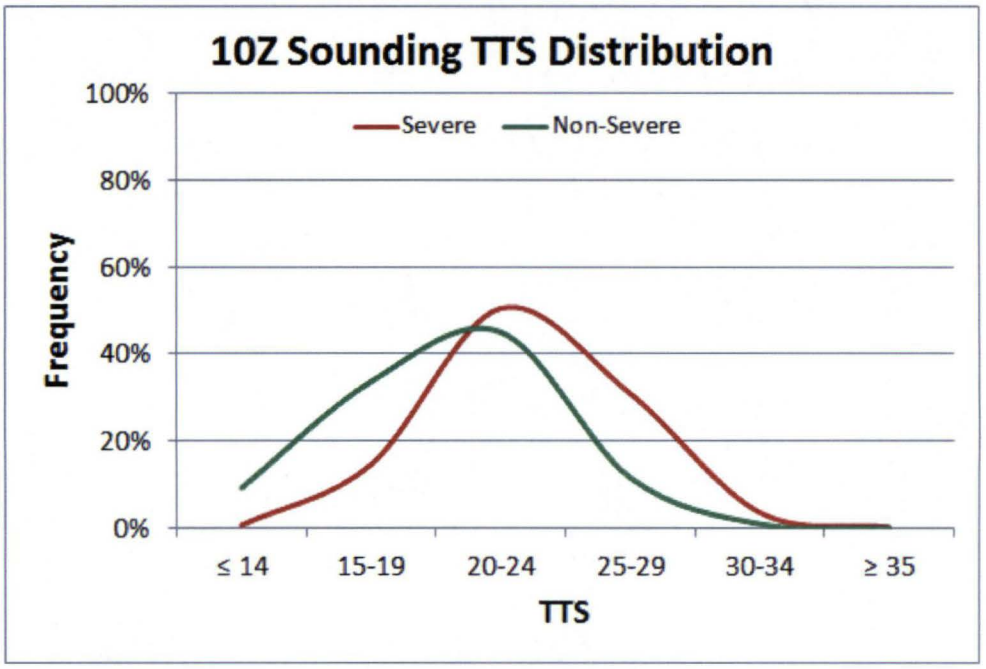


Figure 24. The 1000 UTC sounding-based TTS distribution on days with reported severe weather (red line) and days with no reported severe weather (green line).

6. Future Work

The 45 WS asked if the AMU could assess the benefit of using the 1500 UTC tool over the 1000 UTC tool using several statistical tests to compare the performance of the TTS on days with severe weather when there were both 1000 UTC and 1500 UTC soundings during the POR. Suggestions include creating contingency table statistics, conducting a χ^2 test of severe versus non-severe days for the 1000 UTC and 1500 UTC TTS values, create scatter diagrams of the change in TTS for 1000 UTC and 1500 UTC sounding parameters, and conduct a hypothesis test on the TTS categories. Other metrics such as CSI, TSS, HSS, etc. could also be assessed. Other more objective statistical approaches such as Classification and Regression Trees or multiple logistic regression could be considered. Other approaches using this data set could include using independent performance verification or a resampling approach for tuning the thresholds.

The 45 WS also indicated it would be beneficial to develop guidance using the updated 1000 UTC tool to determine when a 1500 UTC sounding would be needed to assess the severe weather potential for the day. The statistical test results and metrics will determine if the AMU should conduct the work to develop this guidance. If the 1000 UTC tool has little skill in predicting severe weather, then the AMU will not likely be able to develop guidance for determining if a 1500 UTC sounding is needed.

7. Summary and Conclusions

Because people and property at KSC and CCAFS are at risk when severe weather occurs, the 45 WS tasked the AMU to develop a warm season severe weather tool for use in MIDDS based on the late morning, 1500 UTC, XMR sounding. NASA's LSP and GSDO Program along with other programs at KSC and CCAFS use the daily and weekly severe weather forecasts issued by the 45 WS to determine if they need to limit an activity such as working on gantries, or protect property such as a vehicle on a launch pad. The 45 WS requested this severe weather tool be based on the 1500 UTC sounding since they frequently make decisions to issue a severe weather watch and other severe weather warning support products in the late morning because this sounding is more representative of the atmospheric instability than the early morning sounding.

The AMU built upon work in their previous tasks developing severe weather decision aids by using three existing data sets that were compiled during those tasks and updating them with 2011 and 2012 data. Those data sets included upper-level (200 mb) jet stream analyses, severe storm reports and daily flow regimes. The AMU developed two new data sets for this task that included the 1500 UTC XMR soundings and the stability parameters derived from those soundings. The POR included the warm season months in the 24 years from 1989-2012.

The AMU determined a threat score based on individual sounding stability indices and parameter thresholds and, from those, calculated a TTS for every 1500 UTC sounding in the 24-year database and compared the TTS to reported severe weather occurrences on each day with a sounding. They wrote scripts in TIBCO Spotfire S+ and Microsoft Excel VBA to create the 1500 UTC sounding database and make the necessary calculations. They determined a frequency of reported severe weather for each TTS and incorporated the values in an operational tool in MIDDS.

The MIDDS tool consists of a Tcl/Tk script written by the AMU that a user starts from the MIDDS main weather menu. The script automatically retrieves and calculates the required indices and parameters from the sounding and then presents the user with a GUI to choose the 200 mb jet position and 1000-700 mb layer averaged flow regime. This GUI eliminated 83% of the subjective questions posed to the forecasters in the previous MIDDS tool, thereby streamlining the process of running the tool in MIDDS and creating a more objective assessment of the daily warm season severe weather threat.

During the work on this task, the 45 WS asked the AMU if they could replicate the 1500 UTC methodology and MIDDS tool as a replacement for the existing 1000 UTC severe weather tool. With permission from the KSC Weather Office, the AMU was able to do so because most of the 1000 UTC data sets were already available. The AMU determined threat scores and calculated a TTS for every 1000 UTC sounding for the warm season months from 1989-2012 and modified the 1500 UTC MIDDS Tcl/Tk script to process the 1000 UTC XMR soundings.

The AMU delivered both severe weather tools to the 45 WS and they are being used to support daily and launch operations.

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List of Acronyms

45 WS	45th Weather Squadron
AMU	Applied Meteorology Unit
ASCII	American Standard Code for Information Interchange
Avg70RH	Average relative humidity in the 1000-700 mb layer
Avg85RH	Average relative humidity in the 850-500 mb layer
Avg86RH	Average relative humidity in the 850-600 mb layer
CAPE	Convective Available Potential Energy
CAPE FMaxT	CAPE based on the forecast maximum temperature
CAPE Max θ_e	CAPE based on the maximum equivalent potential temperature
CCAFS	Cape Canaveral Air Force Station
CIN	Convective Inhibition
CT	Cross Totals
CSR	Computer Sciences Raytheon
CSV	Comma Separated Value
ER	Eastern Range
GUI	Graphical User Interface
KI	K-Index
KSC	Kennedy Space Center
LI	Lifted Index
MDPI	Microburst Day Potential Index
MIDDS	Meteorological Interactive Data Display System
NW	Northwest
POR	Period of Record
PSU	Plymouth State University
PW	Precipitable Water
QC	Quality Control
RMSE	Root Mean Square Error
SSI	Showalter Stability Index
SW	Southwest
SWEAT	Severe Weather ThrEAT Index
T_{850}	Temperature at 850 mb
T_{500}	Temperature at 500 mb
Tcl/Tk	Tool Command Language and its associated Tool Kit
TI	Thompson Index
TT	Total Totals
TTS	Total Threat Score
UTC	Coordinated Universal Time
VBA	Visual Basic for Applications
VT	Vertical Totals
WarmAdv	Veering winds from surface to 10 kft
XMR	CCAFS rawinsonde 3-letter identifier

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